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13. ABSTRACT *(Maximum 200 words)*

The physics of failure of semiconductor devices, and of the means of simulating it, was studied in order to establish cost-effective methods to design two-and three-terminal semiconductor devices used in amplification, mixing, detection, and oscillation applications. An energy transport simulation code suitable for multi-layered two or three-terminal devices of Si, GaAs, and any other characterizable materials was written and its calculation speed continually enhanced using both physical approximation and numerical sophistication. Results were verified for submicron-scale Si MOSFETs with hot-electron reliability problems, and GaAs MESFETs with high-power microwave impingement problems. An effort to theoretically describe electron transport in hexagonal SiC and related crystals were also begun.

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MODELING FAILURE AND RELIABILITY IN NEW-GENERATION DEVICES

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I. The Problem Studied

The problem originally studied was the prediction of failure and reliability of semiconductor devices based on first principles, i.e., as independent of experimental ab initio information and curve-fitting as possible. The goal of this work was the reduction of device design cost, by reducing rates of failure of devices, due to intentional or unintentional mechanisms, while having to build and test only a minimum number of prototype devices. The use of physics-based semiconductor device simulation for device design was the means to be used to effect this cost reduction.

The scope of this work was later extended to incorprate a study of the electron transport properties, electron energetics, and impact ionization properties, of silicon carbide (SiC).

Specifically, the goals of the work performed were:

1. Evaluation of currently available methods of device analysis and their limits.

2. Indication of useful future directions for device failure prediction and analysis.

3. Development of simulation methods for failure prediction and analysis of such devices as microwave integrated circuits, mixer or detector diodes, memory devices, and transistors, made of silicon, GaAs, or other materials.

4. Determine certain electron transport properties for the SiC polytype with hexagonal crystal structure.

II. Important Results

The accepted means of device simulation, viz., the "drift-diffusion" (DD) method, in which carrier velocity is a single-valued function of electric field; the Monte Carlo method, in which carrier transport under the influence of scattering processes is modeled on a statistical basis within the device, and the energy transport method, which was first developed by the Principal Investigator for application in two-dimensional devices, were compared. By comparison of simulations done using these methods, the drift-diffusion method was found to be inadequate to correctly represent phenomena occurring in three-terminal silicon devices with active lengths under about 1800Å,[1] and compound semiconductor devices with active lengths under about 1 micron. The differences are due to the different energy relaxation processes in these two materials, which have different time constants. These conclusions apply also to two-terminal active microwave devices such as IMPATT or Gunn diodes, and to failure mechanisms in two-terminal passive diodes which might arise from localized heating, either due to external or internal causes. The Failure of three-terminal GaAs devices was studied in some depth, and it was found that explanations of troublesome failure mechanisms could be based on electron transport anomalies.[2,3]

The energy transport device simulation programs we developed were applied to studies of the reliability of submicron-size silicon MOSFETs.[4,5,6] These programs were continually enhanced in order to improve calculation speed.[7,8]

The last year of the grant was occupied by work on the electronic properties of the hexagonal crystalline form of SiC. The objective of this work in particular was to determine the impact ionization properties of the material by means of a Monte Carlo analysis. No such analysis of any hexagonal semiconductor crystal has yet been done, however, so that we have had to develop special techniques to deal with the hexagonal symmetries, and the directional dependencies of the relevant electron scattering processes. We have, to date, developed the relevant scattering formulas and are in the process of coding a one dimensional Monte Carlo simulation for SiC. This work has not yet, however, resulted in a publication.

III. Participating Scientific Personnel

Principal Investigator:

Professor Jeffrey Frey

Graduate Research Assistants:

Lindor Henrickson (M.Sc., 1992)

Zezhong Peng (Ph.D., 1993)

Daniel Kerr (Ph.D. est. 1995)

IV. List of Publications as Referenced

(1)"Enhanced Reliability in Si MOSFETs with Channel Lengths under 0.2 Microns" (with L. Henrickson, Z.Z.Peng, and N. Goldsman), Solid State Electronics 33, (1990) 1275

(2)"Susceptibility of Gallium Arsenide Amplifiers to Single Pulses of Intense Microwave Radiation" (with J. H. Mcadoo, W. Bollen, R. Seeley, and W. Catoe), presented at GOMAC-90 Conference, November 8, 1990

(3)"Rectification Failure in GaAs MESFETs Subjected to Single Pulses of Intense Micrwave Radiation", (with J. McAdoo, W. Bollen, R. Seeley, and W. Catoe), presented at GOMAC-90 Conference, November 7, 1993

(4)"Simulation of Substrate Current Characteristics of Submicron MOSFETs" (with M. Takeda, Z.Z.Peng, and N. Goldsman), Electronics Letters 27 (1991), 144

(5)"MOSFET Hot-Electron Gate Current Calculation by Combining Energy Transport Method with Monte Carlo Simulation" (with S.-L. Wang, L. Henrickson, and N. Goldsman), presented at Proc. 1990 International Electron Devices Meeting, 447

(6)"Physics-Based Simulation of Reliability Performance", presented at Reliability Workshop, Semiconductor Research Corporation, July 17, 1991, Dallas, Texas

(7)"A Physics-Based Analytical/numerical Solution to the Boltzmann Transport Equation for Use in Device Simulation" (with L. Henrickson and N. Goldsman), Solid State Electronics 34 (1991), 389

(8)"Path Integration and Slope Weighting Monte Carlo Methods" (with Z.Z.Peng and N. Goldsman), Proc. Ninth International Conference on the Numerical analysis of Semiconductor Devices and Integrated Circuits (Dublin, 1993), 105